ARMY STTR 14.A
PROPOSAL SUBMISSION INSTRUCTIONS

The approved FY14.A topics solicited for in the Army's Small Business Technology Transfer (STTR) Program are listed below. Offerors responding to the Army STTR FY14.A Solicitation must follow all general instructions provided in the Department of Defense (DoD) Program Solicitation. Specific Army requirements that add to or deviate from the DoD Program Solicitation instructions are provided below with references to the appropriate section of the DoD Solicitation.

The STTR Program Management Office (PMO), located at the United States Army Research Office (ARO), manages the Army's STTR Program. The Army STTR Program harnesses the collective knowledge and experience of scientists and engineers, across nine Army organizations, to identify and put forward research or research and development (R/R&D) topics that are consistent with the mission of the organization and the purpose of the STTR Program – i.e., to stimulate a partnership of ideas and technologies between innovative small business concerns (SBCs) and research institutions (RI) through Federally-funded R/R&D to address Army needs. Information about the Army STTR Program can be found at https://www.armysbir.army.mil/sttr/Default.aspx.

For technical questions about specific topics during the Pre-Solicitation period (03 Feb – 02 Mar 2014), contact the Topic Authors listed as POCs for each topic in the Solicitation. To obtain answers to technical questions during the formal Solicitation on period, visit http://www.dodsbir.net/sitis. For general inquiries or problems with the electronic submission, contact the DoD Help Desk at 1-866-724-7457 (8:00 am to 5:00 pm ET). Specific questions pertaining to the Army STTR Program should be submitted to:

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PHASE I PROPOSAL GUIDELINES

Phase I proposals should address the feasibility of a solution to the topic. Army STTR uses only government employees in a two-tiered review process. Awards will be made on the basis of technical evaluations using the criteria described in this DoD solicitation (see section 6.0) and availability of Army STTR funds. The Army anticipates funding one or possibly two STTR Phase I contracts to small businesses with their research institution partner for each topic. The Army reserves the right to not fund a topic if the proposals have insufficient merit. Phase I contracts are limited to a maximum of $150,000 over a period not to exceed six months.

The DoD SBIR/STTR Proposal Submission system (http://www.dodsbir.net/submission/) provides instruction and a tutorial for preparation and submission of your proposal. Refer to section 5.0 at the front of this solicitation for detailed instructions on Phase I proposal format. You must include a Company Commercialization Report (CCR) as part of each proposal you submit. If you have not updated your commercialization information in the past year, or need to review a copy of your report, visit the DoD SBIR/STTR Proposal Submission site. Please note that improper handling of the CCR may have a direct impact on the review and evaluation of the proposal (refer to section 5.4.e of the DoD Solicitation).

Proposals addressing the topics will be accepted for consideration if received no later **6:00 a.m. ET, Wednesday, 9 April 2014**. The Army requires your entire proposal to be submitted electronically through the DoD-wide SBIR/STTR Proposal Submission Web site (http://www.dodsbir.net/). A hardcopy is NOT required and will not be accepted. Hand or electronic signature on the proposal is also NOT required. Army has established a **20-page limitation** for Technical Volumes submitted in response to its topics. This does not include the Proposal Cover Sheets (pages 1 and 2, added electronically by the DoD submission site), the Cost Volume, or the CCR. The Technical Volume includes, but is not limited to: table of contents, pages left blank, references and letters of support, appendices, key personnel biographical information, and all attachments. The Army requires that small businesses complete the Cost Volume form on the DoD Submission site versus submitting it within the body of the uploaded volume. Proposals are required to be submitted in Portable Document Format (PDF), and it is the responsibility of submitters to ensure any PDF conversion is accurate and does not cause the Technical Volume portion of the proposal to exceed the 20-page limit. **Any pages submitted beyond the 20-page limit, will not be read or evaluated.** If you experience problems uploading a proposal, call the DoD Help Desk 1-866-724-7457 (8:00 am to 5:00 pm ET).

Companies should plan carefully for research involving animal or human subjects, biological agents, etc (see sections 4.7 - 4.9). The few months available for a Phase I effort may preclude plans including these elements, unless coordinated before a contract is awarded.

If the offeror proposes to use a foreign national(s), refer to sections 3.5 and 5.4.c in the DoD Solicitation for definitions and reporting requirements. Please ensure no Privacy Act information is included in this submittal.

If a small business concern receives an STTR award they must negotiate a written agreement between the small business and their selected research institution that allocates intellectual property rights and rights to carry out follow-on research, development, or commercialization (section 10).

PHASE II PROPOSAL GUIDELINES

Commencing with the Phase II's resulting from the STTR FY13.A cycle, all Phase I awardees may apply for a Phase II award for their topic – i.e., no invitation required. Any proposers with Phase I awards from years *prior* to FY13.A, however, must receive an invitation from their awarding office in order to apply for a Phase II. Please note that Phase II selections are based, in large part, on the success of the Phase I effort, so it is vital for SBCs to discuss the Phase I project results with their Army Technical Point of Contact (TPOC). Each year the Army STTR Program Office will post Phase II submission dates on the DoD SBIR/STTR Solicitation web page at http://www.dodsbir.net/solicitation/. The submission period in FY14 will be 30 calendar days starting on or about 07 April 2014. The SBC may submit a Phase II proposal for up to three years after the Phase I selection date, but not more than twice. The Army STTR Program *cannot* accept proposals outside the Phase II submission dates. Proposals received by the Department of Defense at any time other than the prescribed submission period will not be evaluated.

Phase II proposals will be reviewed for overall merit based upon the criteria in section 8.0 of this solicitation. STTR Phase II proposals have 4 sections: Proposal Cover Sheets, Technical Volume, Cost Volume and Company Commercialization Report. The Technical Volume cannot exceed a **38-page** limit which includes the: table of contents, pages intentionally left blank, technical references, letters of support, appendices, technical portions of subcontract documents (e.g., statements of work and resumes) and all attachments. However, offerors are instructed to NOT leave blank pages, duplicate the electronically generated cover pages or put information normally associated with the Technical Volume in others sections of the proposal submission as THESE WILL COUNT AGAINST THE 38-PAGE LIMIT. ONLY the electronically generated Cover Sheets, Cost Volume and CCR are **excluded** from the

38-page limit. As instructed in section 5.4.e of the DoD Program Solicitation, the CCR is generated by the submission website based on information provided by you through the "Company Commercialization Report" tool. **Army Phase II proposals submitted over 38 pages will be deemed NON-COMPLIANT and will not be read or evaluated.**

Small businesses submitting a proposal are also required to develop and submit a technology transition and commercialization plan describing feasible approaches for transitioning and/or commercializing the developed technology in their Phase II proposal. Army Phase II Cost Volumes must contain a budget for the entire 24 month Phase II period not to exceed the maximum dollar amount of $1,000,000 (or $750,00 for Phase II submissions from Phase I contracts awarded prior to FY13). During contract negotiation, the contracting officer may require a Cost Volume for a base year and an option year. These costs must be submitted using the Cost Volume format (accessible electronically on the DoD submission site), and may be presented side-by-side on a single Cost Volume Sheet. The total proposed amount should be indicated on the Proposal Cover Sheet as the Proposed Cost. Phase II projects will be evaluated after the base year prior to extending funding for the option year.

Phase II proposals should be structured as follows: the first 10-12 months (base effort) should be approximately $500,000; the second 10-12 months of funding should also be approximately $500,000. The entire Phase II effort should not exceed $1,000,000. Contract structure for the Phase II contract is at the discretion of the Army's Contracting Officer, and may be affected by the program budget.

DISCRETIONARY TECHNICAL ASSISTANCE

In accordance with section 9(q) of the Small Business Act (15 U.S.C. 638(q)), the Army will provide technical assistance services to small businesses engaged in STTR projects through a network of scientists and engineers engaged in a wide range of technologies. The objective of this effort is to increase Army STTR technology transition and commercialization success. The Army has stationed eight Technical Assistance Advocates (TAAs) across the Army to provide technical assistance to small businesses that have Phase I and Phase II projects with the participating Army organizations.

For more information go to: https://www.armysbir.army.mil/sbir/TechnicalAssistance.aspx

PUBLIC RELEASE OF AWARD INFORMATION

If your proposal is selected for award, the technical abstract and discussion of anticipated benefits will be publicly released via the Internet. Therefore, do not include proprietary or classified information in these sections. For examples of past publicly released DoD SBIR/STTR Phase I and II awards, visit http://www.dodsbir.net/awards.

NOTIFICATION SCHEDULE OF PROPOSAL STATUS AND DEBRIEFS

Once the selection process is complete, the Army STTR Program Manager will send an email to the individual listed as the "Corporate Official" on the Proposal Coversheet with an attached letter of selection or non-selection. The notification letter referenced above will provide instructions for requesting a proposal debriefing. Small Businesses will receive a notification for each proposal that they submitted. The Army STTR Program Manager will provide ***written*** debriefings upon request to offerors in accordance with FAR Subpart 15.5. Please read each notification carefully and note the proposal number and topic number referenced. All communication from the Army STTR Program management will originate from the program specialist's e-mail address.

DEPARTMENT OF THE ARMY PROPOSAL CHECKLIST

This is a Checklist of Army Requirements for your proposal. Please review the checklist to ensure that your proposal meets the Army STTR requirements. You must also meet the general DoD requirements specified in the solicitation. **Failure to meet all the requirements will result in your proposal not being evaluated or considered for award**. Do not include this checklist with your proposal.

1. The proposal addresses a Phase I effort (up to **$150,000** with up to a six-month duration).

2. The proposal is limited to only **ONE** Army Solicitation topic.

3. The technical content of the proposal includes the items identified in Section 5.4 of the Solicitation.

4. STTR Phase I Proposals have four sections: Proposal Cover Sheets, Technical Volume, Cost Volume and Company Commercialization Report.

5. The Cost Volume has been completed and submitted for Phase I effort. The total cost should match the amount on the cover pages.

6. Requirement for Army Accounting for Contract Services, otherwise known as CMRA reporting is included in the Cost Volume (offerors are instructed to include an estimate for the cost of complying with CMRA – see website at https://cmra.army.mil/).

7. If applicable, the Bio Hazard Material level has been identified in the Technical Volume.

8. If applicable, plan for research involving animal or human subjects, or requiring access to government resources of any kind.

9. The Phase I Proposal describes the "vision" or "end-state" of the research and the most likely strategy or path for transition of the STTR project from research to an operational capability that satisfies one or more Army operational or technical requirements in a new or existing system, larger research program, or as a stand-alone product or service.

10. If applicable, Foreign Nationals are identified in the proposal. An employee must have an H-1B Visa to work on a DoD STTR contract.

Army STTR 14.A Topic Index

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Army STTR 14.A Topic Descriptions

A14A-T001 TITLE: High Fidelity In/Above-Horizon Rotorcraft Noise Measurement System

TECHNOLOGY AREAS: Air Platform

OBJECTIVE: To develop measurement techniques to obtain quantitative acoustic data (pulse shape and level) of helicopter external noise radiation, forward and in or near in-plane with respect to the horizon. The data gathering method, and its associated technologies, shall address efforts to minimize distortions from ground and/or obstruction reflections, and from high ambient/background/self noise. This new capability is sought to augment existing measurement techniques limited to below horizon and to better characterize helicopter noise directivity patterns for use in acoustics modeling software, such as the NASA/Army's Rotor Noise Modeling1 (RNM). Above the horizon-plane acoustics characterization can be important for detection, especially when enemy observers stationed are at higher elevations than the helicopter flight altitudes.

DESCRIPTION: External harmonic noise generated during helicopter operations is known to be dependent on many operational and design variables and is strongly directional. Certain regimes of operations, particularly at high speeds, result in known acoustics radiation (primarily due to thickness and/or delocalized shocks), that are "symmetrical" above and below the tip-path-plane of the rotor. However, at lower speeds, contribution from the lift loading noise component becomes more significant and is known to change sign above/below the tip-path-plane. Such a change in polarity can cause the loading noise component to add or subtract differently from the thickness noise component, resulting in different pulse shapes and levels depending on the elevation angle of the measurement location with respect to the rotor.

Current state-of-the-art acoustics measurement techniques used by DoD and NASA rely on ground based noise measurements 2-4 to characterize their fleet of operational helicopters. Typically, the setup involves taking data with a fixed array of flush-mounted, ground microphones when a helicopter is flown over the array at specified operational conditions (airspeed, descent angle, gross weight, etc.). Measured data are stored as a function of these flight conditions and represented as a simple compact moving noise source – one that has a noise directivity pattern that is developed from these measurements. These acoustic spheres are then mathematically extrapolated, with appropriate propagation effects, to obtain true radiated far-field noise at a chosen observer location. The results are used to determine aural/electronic detection distance (or probability) associated with the operating state of the helicopter.

This procedure works reasonably well for observers underneath the helicopter, but not for observers/measurement locations near or above the horizon (such as noise measurement obtained from tall microphone towers). Ground reflections from intense out-of-plane rotor noise tend to interfere with direct in-plane noise radiation – often rendering the in-plane noise measurement to be highly questionable. This effect is particularly severe for, long range, low frequency sound measurement, where the direct and ground reflected sound paths are nearly equal in distance.

To facilitate the need for better in- and/or near-horizon helicopter noise measurement, the Army is soliciting new methods and/or procedures of measuring noise that address the following requirements:

- Enable acoustics measurement forward of the helicopter, in and near in-plane of the horizon (within 30° above and below the horizon plane), at source-to-microphone distances less than 2500 ft. (to minimize sound propagation effects).
- Minimize effects of ground reflections so that reflections are at least 10 dB lower than the direct path signals.
- Must have sufficiently low ambient/background noise to attain at least 10 dB signal-to-noise ratios.
- Provide time and position tracking for synchronization with measured helicopter operating state.

PHASE I: The objective of Phase I is to demonstrate the feasibility of gathering harmonic noise measurements near or above the horizon. A preliminary design of the system shall be proposed that includes all necessary software and hardware. The design should make sure that high quality data can be obtained including; adequate signal to background noise estimates, accurate positioning of the equipment, and adequate estimates of the key operational parameters. A proof of concept test is recommended to validate key design specifications. Leveraging on rotorcraft external noise prediction capabilities, to establish measurement envelopes, requirements and guidelines (e.g. frequency limits, amplitude bandwidth, resolution etc.), for this new capability are encouraged.

PHASE II: The objective of Phase II is to develop a prototype breadboard measurement system that can be used to measure rotor harmonic noise near to and above the horizon. The improved system design will be refined based upon the data gathered in Phase I. The design will enable harmonic noise data to be gathered in an efficient and cost effective manner. All data gathering software and hardware will be designed to interface with necessary on-board helicopter instrumentation and be user friendly. The complete system will be operationally tested and evaluated by the contractor in a noise data-gathering test (to be determined) with participation from Army personnel. The contractor will support and conduct such testing and be an integral part of the evaluation.

PHASE III DUAL USE APPLICATIONS: This new measurement system is useful in a broad range of military and civilian security applications where self noise monitoring, surveillance, detection and tracking of inbound threats are desirable. A platform/airborne-based solution, if proposed, will be useful to all branches of the Armed Forces that intend to operate air vehicles in noise sensitive environments. This new capability enables self noise tracking that can lead to development of cabin displays/piloting cues for pilot training and mission execution to achieve real-time low noise flight operations. Alternatively, a ground-fixed solution is envisioned to improve threat surveillance and passive tracking technologies. Examples include the ability to augment existing aerostat capabilities to enhance force protection through better performance of the aural detection/IFF system, and to assist border patrol in monitoring illegal trafficking activities with better passive acoustic surveillance capability with minimal distortions from terrain effects. This new measurement capability will also help validate/understand rotary-wing aeroacoustics above the horizon and facilitate development of complete, three-dimensional aural characterization of air vehicles highly sought after by DoD and commercial mission planning tool developers. It is envisioned that these findings will also provide useful guidelines for interpolating existing below-the-horizon noise database, previously collected by NASA, Army AMRDEC etc., to locations above-the-horizon, reliably and accurately.

REFERENCES:
1. Sickenberger, R., "Modeling Helicopter Near-Horizon Harmonic Noise due to Transient Maneuvers," Ph.D. Thesis, University of Maryland, Department of Aerospace Engineering, 2013.

2. Greenwood, E., Schmitz, F., and Sickenberger, R., "A Semi-Empirical Noise Modeling Method for Helicopter Maneuvering Flight Operations," American Helicopter Society 68th Annual Forum, Fort Worth, TX, May 1-3, 2012.

KEYWORDS: rotor, helicopter, aural, noise, acoustics, sound measurement, sound reflection, survivability

A14A-T002 TITLE: Ultrafast Physical Random Number Generation Using Chaos

TECHNOLOGY AREAS: Sensors

OBJECTIVE: Modern cyber security relies fundamentally on the generation of random numbers, e.g., as secret keys or passwords [1]. Traditionally exploited sources of true random numbers (such as user interaction) cannot provide sufficient output at the ever-increasing rates required for secure communications within large networks (e.g., cloud computing). Recently, fast generation of random numbers has been demonstrated in a number of laboratory experiments involving chaotic electronic or photonic devices [2, 3, 4]. The sensitivity of chaotic systems to perturbations makes them effective amplifiers of microscopic noise. The objective of this project is to develop a practical chaotic device for ultrafast generation of random numbers, a key component for ensuring the integrity of next-generation secure communication and networking.

DESCRIPTION: Numerous devices for generating high bandwidth chaotic oscillations have been developed in recent years. As chaotic dynamical systems, the macroscopic oscillations of these systems are highly dependent on microscopic perturbations. This sensitivity makes them effective transducers for bringing high-bandwidth, microscopic entropy sources to the dynamic range of macroscopic detectors. In laboratory experiments, both electronic and photonic chaotic devices have been shown to generate bit streams at gigabit rates that pass NIST-type benchmarking tests [2, 3, 4]. Recently, a theoretical description of the process by which chaos amplifies microscopic noise has emerged putting hardware random number generation on a firm scientific foundation [5]. To capitalize on these discoveries, it is sought to develop a practical physical random number generator that exploits chaos to amplify microscopic noise, outputs true random numbers at gigabits rates, and is easily integrated into conventional digital technology. Chaotic devices which require minimal post-processing to remove bias and correlation are especially desirable. Also desirable is robustness to changes in the macroscopic noise environment. The primary intent of this solicitation is to develop a critical component required to enable subsequent development of next-generation secure network technology. As such, the solicitation is not limited to a particular application or performance specification.

PHASE I: Conduct a design study with detailed model development for a physical realization of a chaotic random number generator. Prototype chaotic oscillators will be constructed, and testing will identify a preferred operating point. Simulations of a complete random number generation scheme will be used to identify a preferred system design. Consideration will be given to cost and reliability in oscillator designs, ease of integration with digital electronics, and the extent of the theory of operation.

PHASE II: Finalize a random number generator design and fabricate an easily reproducible device suitable for use in brass-board secure network systems. Performance metrics will establish entropy rate, post-processing requirements, robustness, and integration costs. Potential military and commercial applications will be identified and targeted for Phase III exploitation and commercialization.

PHASE III DUAL USE APPLICATIONS: The development of a practical ultrafast random number generator enables next-generation network security and encryption. These technologies offer potential benefits across a wide swath of communications and sensor networks for both military and civilian applications.

REFERENCES:
1. A. J. Menezes, Handbook of Applied Cryptography, CRC, Boca Raton, FL (1993).

2. A. Uchida, K. Amano, M. Inoue, K. Hirano, S. Naito, H. Someya, I. Oowada, T. Kurashige, M. Shiki, S. Yoshimori, K. Yoshimura, and P. Davis, “Fast physical random bit generation with chaotic semiconductor lasers,” Nature Photonics, vol. 2, pp. 728-732 (2008).

3. D. P. Rosin, D. Rontani, and D. J. Gauthier, “Ultrafast physical generation of random numbers using hybrid Boolean networks,” Phys. Rev. E, vol. 87, art. 040902(R) (2013).

4. W. Li, I. Reidler, Y. Aviad, Y. Huang, H. Song, Y. Zhang, M. Rosenbluh, and I. Kanter, “Fast Physical Random-Number Generation Based on Room-Temperature Chaotic Oscillations in Weakly Coupled Superlattices,” Phys. Rev. Lett., vol. 111, art. 044102 (2013).

5. T. Harayama, S. Sunada, K. Yoshimura, J. Muramatsu, K. Arai, A. Uchida, and P. Davis, “Theory of fast nondeterministic physical random-bit generation with chaotic lasers,” Phys. Rev. E, vol. 85, art. 046215 (2012).

KEYWORDS: chaos, cryptography, oscillator, random, entropy

A14A-T003 TITLE: <u>Compressive Sampling Applied to Millimeter-wave Single Detector Imagers</u>

TECHNOLOGY AREAS: Sensors

The technology within this topic is restricted under the International Traffic in Arms Regulation (ITAR), which controls the export and import of defense-related material and services. Offerors must disclose any proposed use of foreign nationals, their country of origin, and what tasks each would accomplish in the statement of work in accordance with section 3.4 of the solicitation.

OBJECTIVE: To design, construct, and deliver a millimeter-wave imager that uses compressive sampling techniques to minimize the amount of time required for a single detector to render an image.

DESCRIPTION: Non-ionizing millimeter-wave (mmw) and terahertz (THz) imagers are increasingly being recognized as promising alternatives to X-ray imagers for non-destructive testing of objects to identify obscured failures, screening passengers at airports for concealed weapons, and assisting pilots as they navigate in visually degraded environments. As technological advances increase the power of mmw/THz sources and the sensitivity of mmw/THz detectors, one of the greatest remaining challenges facing mmw/THz imaging is cost, particularly for heterodyne receivers. Consequently, the lack of available sensitive focal plane arrays results in images rendered slowly by single detectors coupled to a scanning receiver dish or antenna structure. Thus, it is not uncommon for a high-resolution image to take hours or days to render, especially at the higher frequencies.

Compressive sensing techniques enable simultaneous compression and sensing of signals traditionally acquired with oversampling based on the existence of a sparse signal representation within a set of projected measurements. These techniques have shown great promise to reduce the amount of information required to acquire and reconstruct information from radio frequency, synthetic aperture radar, and electro-optical sensors sources, and they offer the opportunity to accelerate the rendering of mmw/THz images dramatically. For instance, reasonably accurate image reconstructions are possible by illuminating the scene with a sequence of coded aperture wavefronts produced through a dynamically addressable spatial light modulator [1]. Although there is no satisfactory equivalent of a dynamic spatial light modulator or sensitive, high pixel density CCD detector array in the mmw/THz spectral region, it could be argued that the need for compressive sampling techniques is far greater for the reasons outlined above.

Therefore, a need exists to develop new compressive sampling techniques and associated optics so that compressive sampling may be used to reconstruct images in the mmw/THz spectral region quickly using a single detector [2]. Various approaches have been attempted, including holographic reconstructions [3], a series of random, static masks or cyclic Hadamard matrices [4,5], and metamaterial antennas that produce known radiation patterns [6]. Although much work in this spectral region involves broadband sources, such as terahertz time-domain techniques, solutions proposed here must use only highly coherent, narrowband (< 1 MHz linewidth) sources that, if necessary, may be amplitude, frequency, and/or phase modulated. The proposed solution should additionally contain a single heterodyne receiver with >80 dB of dynamic range independently or in conjunction with a user-supplied vector network analyzer. It is anticipated that the solution will involve both novel compressive sampling methodologies as well as hardware development to realize and execute these methodologies with as much speed and fidelity as possible. Ideally, there will be no need to scan the detector, which may be viewing the target in transmission or reflection.

PHASE I: Develop a compressive sensing methodology and design an imager capable of rendering a high fidelity image quickly in the mmw (or sub-THz) spectral region (i.e. 35 GHz – 300 GHz) using a single heterodyne receiver. Because this is a proof-of-concept demonstration, the performer is free to select the frequency region of interest and may impose any combination of frequency, amplitude, and phase modulation and scanning desired in conjunction with any approach to wavefront encoding and/or image reconstruction necessary to render high fidelity images much faster than can be achieved through simple raster scanning of the heterodyne receiver. Preference will be given to techniques that could work at any frequency in this region.

PHASE II: Construct, characterize, and optimize the performance of a mmw (or sub-THz), single detector imager based on the design developed in Phase I. The figures of merit that must be used to characterize the performance of the compressive imager are the fidelity degradation and speed acceleration as compared to an image rendered through simple scanning of the single detector. The complete, proof-of-concept compressive imager using a single mmw (or sub-THz) detector will be delivered to AMRDEC at the end of Phase II.

PHASE III DUAL USE APPLICATIONS: Advance the technology readiness level of the proof-of-concept delivered in Phase II to an affordable, packaged, marketable imager that may be used by a broad commercial market for non-destructive testing of obscured objects.

REFERENCES:
1. E.J.Candes, M.B. Wakin, IEEE Signal Processing Magazine 25, p. 21 (2008).

2. M.F. Duarte, M.A. Davenport, D. Takhar, J.N. Laska, T. Sun, K.F. Kelly, R.G. Baraniuk, IEEE Signal Processing Magazine 25, p. 83 (2008).

3. C.F. Cull, D.A. Wikner, J.N. Mait, M. Mattheiss, D.J. Brady, Applied Optics 49, p. E67 (2010).

4. W.L. Chan, K. Charan, D. Takhar, K.F. Kelly, R.G. Baraniuk, D.M. Mittleman, Applied Physics Letters 93, p. 121105 (2008).

5. L. Spinoulas, J. Qi, A.K. Katsaggelos, T.W. Elmer, N. Gopalsami, A.C. Raptis, Applied Optics 51, p. 6335 (2012).

6. J.Hunt, T. Driscoll, A. Mrozack, G. Lipworth, M. Reynolds, D. Brady, and D.R. Smith, Science 339, p. 310 (2013).

KEYWORDS: Compressive sampling, compressive imaging, millimeter wave imaging, terahertz imaging

A14A-T004 TITLE: <u>High Gain, High Power PCSS with Integrated Monolithic Optical Trigger</u>

TECHNOLOGY AREAS: Materials/Processes

The technology within this topic is restricted under the International Traffic in Arms Regulation (ITAR), which controls the export and import of defense-related material and services. Offerors must disclose any proposed use of foreign nationals, their country of origin, and what tasks each would accomplish in the statement of work in accordance with section 3. of the solicitation.

OBJECTIVE: Develop a photoconductive semiconductor switch (PCSS) with an integrated monolithic semiconductor laser array trigger capable of hold-off voltage greater than 30KV, current conduction > 1 kA for >20 ns, and jitter <100ps (relative to the external laser driver) . The PCSS must be triggered without an external laser and the PCSS-laser array package must have long device life (> 100E6 shots).

DESCRIPTION: Conventional pulsed power systems have primarily used spark gaps in various forms as the main switches for high voltage (>10 KV) and high current (>10 KA) operations. Spark gap switches have limitations in terms of their triggering requirements, timing jitter and switching time and have poor reliability. Moreover, in most cases they require using oil or high-level of pressurization for achieving high hold-off voltages in an electrical mechanical switch, and are size and weight prohibitive, due to the associated sub-systems required for controlling thermal and electrical breakdowns. Gallium arsenide (GaAs) -based PCSS at Sandia National Laboratory (per references below) has been shown capable to operate at useable high voltage applications with switch rise times < 0.4 ns and timing jitter of < 100 ps. Moreover, they have been shown to conduct current in filaments which can be triggered with optical pulses < 100 nanojoule (nJ) and stay on as long as the circuit maintains an electric field across the switch > 4-6 kV/cm (high-gain avalanche mode). Due to these two properties, these switches have been shown to be triggered much more efficiently than conventional linear PCSS. They should not require an external optical delivery system to provide high energy optical triggers for reliable low jitter operation. This R&D effort will further advance the PCSS development by incorporating the optical triggering into the device, eliminating the external laser systems and associated alignment issues for ruggedized military operations. An integrated monolithic optical trigger/switch will render a more robust, reliable, and longer lived building block for high voltage and high current pulsed power systems.

PHASE I: Conduct a feasibility study and design to implement the concepts for integrating a PCSS (capable of holdoff voltages > 30KV at > 50kV/cm) with a monolithic semiconductor laser array (to provide the optical trigger) in a single integrated package. Prepare and submit the study and detailed switch module design with a preliminary proof of concept demonstration as approved and agreed with the sponsor.

PHASE II: Establish performance parameters through experiments and prototype fabrication of a single high-gain PCSS-semiconductor laser array trigger module capable of operating in a high gain mode holding off >30 kV DC and trigger multiple current sharing filaments with a conduction pulse width of greater than 20 ns and a timing jitter of < 0.5 ns. Demonstrate the capability to operate at rep rates of up to 1 KHz and of over 10,000 shot life-time. Establish fabrication and production processes to scale the PCSS-semiconductor laser array to trigger enough current sharing filaments to switch 1 kA per module at the above hold-off, pulse width, jitter, and shot life-time.

PHASE III DUAL USE APPLICATIONS: This topic will provide the capability to control and shape a high voltage pulse with optical controlled PCSS trigger, improving the size, weight, power and operational obstacles associated with thermal, electrical, vibration. This topic investigates an approach to eliminate a number of traditional obstacles via optical triggering and further improving performance by incorporation of the optical trigger into a single device. Military applications will include UWB (UltraWideband) pulse sources and ground penetration radar. The development will provide the basis for next generation high voltage system control and support to IED Neutralization Technologies and ground based Army systems within ARDEC, Armament Research and Development Command.

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KEYWORDS: photoconductive semiconductor switch, hold-off voltage, jitter, trigger

A14A-T005 TITLE: Ultra-Coherent Semiconductor Laser Technology

TECHNOLOGY AREAS: Sensors

OBJECTIVE: To develop semiconductor laser with an order of magnitude decrease in linewidth relative to the state-of-the-art in distributed feedback lasers

DESCRIPTION: Distributed feedback (DFB) semiconductors lasers have been used for several decades as narrow linewidth sources used in fiber optic based telecommunications [1-3]. Advancements in laser coherence (or linewidth narrowing) beyond the 100 kHz regime have been achieved with use of fiber lasers but until recently have not been seen in semiconductor lasers [4]. In order to reduce the linewidth further, waveguiding and filtering theory with coupled microresonators and slow-light can be used [5-7]. Use of silicon waveguides for the slow light resonator can be made to take advantage of the advances made in processing of it as well as the use of it for integrated circuits. Then, by using wafer bonding hybridization techniques [8] one can mate a III-V semiconductor gain region to the slow-light microresonator and create a new silicon photonic compatible laser. Such work is what is requested to pursue here for next generation telecommunications systems and other long coherence length propagation laser applications. Particular needs in telecommunications are for systems which utilize extremely narrow linewidth lasers with phase-shift keying modulation schemes that utilize the phase of the light to increase the channel bandwidth. Lidar and spectroscopic systems which use long coherence lengths to gather more sensitive range resolution or detection may also benefit from such improvements.

PHASE I: To demonstrate designs and proof of principle of semiconductor lasers with linewidths below 20 kHz. Prototype examples showing the potential of the fabrication processes to be used for the larger wafer scale (or quarter of 2” wafer) processes should be developed. Tolerances in process variation from lithography or etching should be investigated to fit within the design to create a yield of at least 10% of the lasers with linewidths under 20 kHz and two-thirds under 60 kHz

PHASE II: To further the designs of phase I with additional waveguide or active regions that push the linewidths below 10 kHz. In this phase fabrication of many lasers per quarter wafer should be investigated to examine the yield at given linewidth benchmarks. Goals of achieving 10% of the lasers with linewidths < 5 kHz and two-thirds below 20 kHz would be beneficial towards the goal of achieving equality with fiber laser technologies.

PHASE III DUAL USE APPLICATIONS: Development of a high yield ultra-narrow linewidth semiconductor laser process with sub-5 kHz linewidths for use in advanced telecommunications and ladar systems. In particular, coherent communications with use of phase-shift-keying provide an opportunity for overall data rates that scale as the inverse of the linewidth. Other uses as replacements of fiber lasers for coherent ladar systems and high resolution spectroscopy laser sources are desirable.

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KEYWORDS: semiconductor laser, narrow linewidth, coherence length

A14A-T006 TITLE: Powerful Source of Collimated Coherent Infrared Radiation with Pulse Duration Fewer than Ten Cycles

TECHNOLOGY AREAS: Sensors

OBJECTIVE: Develop a compact source of few cycle collimated coherent optical pulses with center wavelength in the range 8 to 12 microns and with single pulse energy greater than 10 microjoules.

DESCRIPTION: Lasers with sub-picosecond pulse periods, operating at wavelengths ranging from ultraviolet to mid-infrared (mid-IR), are used extensively for a variety of applications including ultrafast spectroscopy, attosecond pulse generation, coherent XUV and X-ray generation, laser cooling and trapping, femto-second chemistry, micromachining, frequency comb generation, laser filamentation in the atmosphere, medical imaging, eye surgery, terahertz generation, remote sensing of chemical or biological materials, and laser approaches for particle acceleration. Over the last decade, a major research thrust in ultrafast laser technology has been to shorten the pulse widths of these sources to only a few periods (i.e. cycles) at the center wavelength [refs 1-5]. The corresponding improvements in temporal resolution and spectral bandwidth have revolutionized our ability to investigate and understand dynamical behaviors on the fastest timescales.

Pulse widths of fewer than ten cycles are routinely achieved for wavelengths < 1 micron, but comparatively little work has been done to develop few cycle laser pulses in the IR. Of particular interest is the development of powerful sources of radiation within the 8-12 micron wavelength region with pulse widths fewer than 10 cycles. The goal of this STTR is to design and construct a reliably stable source of spatially and temporally collimated coherent optical pulses, with ultrashort pulse lengths <10 cycles, pulse energies > 10 microJ, and pulse repetition rates of 10 Hz or greater. Among the many possible approaches for sources of few cycle spatially and temporally coherent light at these wavelengths are mode locking an IR laser, wavelength conversion from an IR or mid-IR laser using optical parametric amplification, or other non-linear up- or down-conversion processes [refs 1-5].

Such sources may be used for high harmonic generation resulting from the propagation of a ultrashort laser pulse in pressurized gas to create bright coherent x-rays with energies greater than 1 keV [ref 3]. The efficiency of this process is in part dependent on a phase matching condition that is expected to be more favorable at these IR wavelengths. In addition, by spectrally tailoring ultrafast IR pulses, specific chemical bonds or molecular features may be excited while suppressing others, allowing unprecedented insights into molecular reaction dynamics. Other applications of ultrafast IR laser pulses include micromachining of metal surfaces without damaging IR-transparent coatings, and laser surgery that minimizes energy deposition or Rayleigh scattering while permitting precise local control (such as in the sclera for treating glaucoma). Another emerging application is the stable creation and control of long plasma filaments in the atmosphere that may be used for remote sensing of chemical and biological species.

In all of these application areas there is theoretical reason to believe that extending the center wavelength to the long wavelength IR (8-12 microns) will result in major enhancements of the application capability.

PHASE I: Demonstrate feasibility by designing a spatially and temporally coherent pulsed source of IR radiation with center wavelength in the 8-12 micron wavelength region with pulse widths <10 cycles, pulse energies > 10 microJ (> 100 microJ desirable), and pulse repetition rates of at least 10 Hz. The operation of the source must be engineered to maximize stability and simplify alignment to achieve optimal performance. Employ analytical tools to verify the feasibility of the design concept and to identify risk issues in the design. The sensitivity to mechanical and thermal stability must be assessed and minimized, and a means for monitoring the performance of the laser must be identified. Conduct bench scale laboratory experiments to resolve key design risk issues. To minimize risk, the design must be based on commercially available or readily manufacturable components to the extent possible, and plans to fabricate or procure unique components must be specified.

PHASE II: Based on the design in Phase I, construct, demonstrate, and deliver to a designated DoD laboratory a prototype packaged source of spatially and temporally coherent pulses with center wavelengths in the 8-12 micron region with pulse widths < 10 cycles, pulse energies > 10 microJ (> 100 microJ desirable), and a pulse repetition rate of at least 10 Hz.

PHASE III DUAL USE APPLICATIONS: Building on this proof of concept demonstration, develop a marketable, packaged system with IR pulse energies of 1 mJ or greater, including alignment and characterization tools, software, instruction material, and training material of commercial standard. It is expected that in addition to military laboratory interest, a market will exist first in academic and industry laboratories exploring the potential applications noted above, and ultimately for commercial and military systems exploiting them.

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KEYWORDS: ultrashort pulse laser, femtosecond laser, long wavelength IR laser, high power laser, few cycle pulsed laser, few cycle IR laser, ultrafast pulsed laser, infrared pulsed laser

A14A-T007 TITLE: High-Performance Magnesium Alloys and Composites by Efficient Vapor Phase Processing

TECHNOLOGY AREAS: Materials/Processes

OBJECTIVE: Design and build a scalable prototype process for generating magnesium vapor at low cost and with low cradle-to-gate energy usage, and use it to fabricate novel light-weight high- performance alloy components with properties better than that achievable with conventional melt alloys.

DESCRIPTION: Magnesium is the lowest-density structural metal, with bending stiffness-to-weight rivaling the best composites. It also machines quickly, has better dimensional stability and solvent resistance than most polymers, and is compatible with metallurgical operations such as deformation and thermal processing. Although conventional magnesium cast and wrought alloys exhibit reasonable strength and corrosion resistance, there are opportunities for substantial improvement using new alloys or composites that may only be made by vapor phase processing techniques. For example, magnesium-matrix fiber composites can attain better quality and finer-grained structure control from a vapor source by coating individual fibers and then consolidating them, avoiding non- wetted voids between fibers. One can also use vapor co-deposition to form non-equilibrium alloys: alloys with elements immiscible with magnesium, and/or whose melting point is above magnesium's boiling point, such that conventional melt alloy processing is impossible. Typically, metal evaporation is extremely energy-intensive, and this production route is cost-prohibitive for practical use in structural components and armor applications. Therefore, the goal of this project is to develop new scalable, energy-efficient, cost-effective magnesium vapor production processes for making bulk non-equilibrium alloys, composites, and other applications, and use them to demonstrate manufacturing of a light-weight high-performance component for Army use.

PHASE I: Produce ten grams of magnesium vapor using the candidate process. Select a candidate material product with potential U.S. Army applications containing at least 80% magnesium by weight which is suited to this vapor production technology. Show rough physics, energy and cost models indicating low production cost and energy use at scale.

PHASE II: Demonstrate production of magnesium at 10 kilogram scale, and fabricate at least 100 g of the candidate material product which cannot be made by conventional melt processing. Show a rough design of a pilot-scale production facility and provide detailed physics, energy and cost modeling.

PHASE III DUAL USE APPLICATIONS: This system will be used to generate novel non-equilibrium alloys to support multiple Mg-alloy R&D efforts at ARDEC (ultralightweight small arms components) and ARL (Materials in Extreme Dynamic Environments (MEDE) programs). The system and materials would also feed into DOE Office of Energy Efficiency and Renewable Energy (EERE) efforts to introduce Mg-alloys into vehicle technologies to meet CAFÉ standards for fuel efficiency.

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KEYWORDS: magnesium, manufacturing, metal vapor, vapor co-deposition, non-equilibrium alloys, metal-matrix composites

A14A-T008 TITLE: Low Power Monolayer MoS_2 Transistors for RF Applications

TECHNOLOGY AREAS: Materials/Processes

The technology within this topic is restricted under the International Traffic in Arms Regulation (ITAR), which controls the export and import of defense-related material and services. Offerors must disclose any proposed use of foreign nationals, their country of origin, and what tasks each would accomplish in the statement of work in accordance with section 3.4 of the solicitation.

OBJECTIVE: To demonstrate the feasibility of manufacturing large area, high frequency single crystal monolayer molybdenum disulfide (MoS2) transistors.

DESCRIPTION: Monolayer two-dimensional (2D) material field effect transistors (FETs) can exhibit excellent scalability as needed for very high frequency applications because the transistor action remains confined to a single atomic layer. This will allow good gate control at high cutoff frequencies as needed for very high bandwidth communication systems as well as very sensitive sensor systems. This is an advantage over silicon based FETs which have at the Si/SiO2 interface an electron mobility comparable to the MoS2 phonon limited room temperature mobility. Due to the thin (6.5 angstrom) carrier transport region and strength that is 30 times stronger than steel, these transistors are also very promising for flexible electronics that can survive impacts, and/or can be integrated into clothing or molded to bendable surfaces.[1] It has also been indicated that the breakdown current density of MoS2 is roughly 5×10 exp 7 A/cm2 which is 50 times higher than copper leading to potentially increased reliability.[2]

MoS2 transistors have been demonstrated and promise excellent performance with low subthreshold slope, good on currents and exemplary transconductance comparable to other low dimensional devices. However, there are still many issues requiring further investigation to improve the performance and make this family of transistors ready for system applications. For high frequency circuit applications, the contact resistance needs to be reduced over that seen in conventional contact materials such as Ti/Al, using more exotic metals such as scandium or monolayer graphene. Furthermore, the metal to MoS2 interface is strongly impacted by Fermi level pinning. Besides this, the mobility measured in these monolayers has varied greatly in the literature, though it is expected to be close to 200 cm2/V/s when using high-K dielectrics that reduce screening and Coulombic scattering.[3] However, closer attention needs to be paid to how these mobility values are measured.[4] Furthermore, doping of the MoS2 structure to enhance free carrier concentration and improve the current density needs to be investigated.

MoS2 is also understood to have a relatively heavy effective mass leading to several benefits such as prevention of tunnel current when device is off, greater on/off current ratios, and larger on currents due to the resulting larger density of states influencing the Fermi level position. However, related to the larger effective mass, the quantum capacitance is larger and this can affect gate control.[5] Gating issues can also show up as hysteresis due to the interface and dielectric quality of the materials surrounding the monolayer channel material leading to poor switching and high frequency performance. It is anticipated that using advanced deposition techniques for the dielectrics and contacts will allow the development of MoS2 FETs with unprecedented RF performance.

PHASE I: Proposers will demonstrate viable large area MoS2 growth technique on a device quality substrate, along with a top and bottom gated monolayer single crystal MoS2 transistors fabrication technology for RF applications using either CVD or exfoliated MoS2 for the active region. A key part of this phase is developing good ohmic source and drain contacts that allow an RF performance better than Ft=5 GHz and Fmax of 5 GHz. The devices should also contain low hysteresis dielectric layers for top and bottom gate contacts with low gate and drain lag. These devices should handle DC power of 10 µW and potentially an RF power of 1.0 µW. The Phase I work should include full characterization of the MoS2 starting materials and the subsequently fabricated transistors. This should include the Hall and field effect mobilities, switching times, cutoff frequencies, source and drain contact resistances, transistor transconductance, maximum current, and breakdown voltage. Also, an outline of the plan to move forward to meet the goals of Phase II should be provided by the end of Phase I. For the RF characterization, on wafer 50-Ohm ground-signal-ground test fixtures should be used along with de-embedding structures for accurate characterization of the intrinsic and extrinsic transistor gain and frequency performance.

PHASE II: The small business will build on the innovations identified in Phase 1 and develop the ability to consistently fabricate complete RF amplifier circuits providing RF gain at frequencies above 1 GHz using CVD grown single crystal monolayer MoS_2 transistors for the transistor's active region. Device performance should be demonstrated on-wafer by probing in a 50 ohm environment with ground-signal-ground probes. Growth and fabrication should be optimized in collaboration with the university partner so that a peak transconductance of 100 mS/mm can be consistently met along with an on/off ratio greater than 10 exp5 and good pinchoff performance. The circuit should demonstrate at 5 GHz an RF output power of 10 µW, and a power gain of 10 dB. The transistors should also demonstrate an Fmax greater than 20 GHz. RF performance comparisons with existing low dimensional technology should be done. Towards the end of the program the device periphery should be pushed beyond 50 µm.

PHASE III DUAL USE APPLICATIONS: Phase III will involve refinements and demonstrations of an RF circuit applicable to military systems including appropriate packaging. Documentation to ISO standards and refinement of the manufacturing processes will be performed and repeated to establish a commercially scalable manufacturing process. Additional reliability testing will be performed to conform to commercial and military standard test practices.

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KEYWORDS: RF Amplifier, Oscillator, Transition metal dichalcogenide, CVD, FET, HEMT, MOSFET

A14A-T009 TITLE: Technology to Regulate Circadian Rhythm for Health and Performance

TECHNOLOGY AREAS: Human Systems

OBJECTIVE: DoD is concerned with circadian rhythm misalignments as they are known to affect judgment and planning, as well as psychomotor skills, and can lead to PTSD. The objective of this topic is to develop and demonstrate a wearable device that can be utilized as a personal circadian rhythm monitor and regulation device capable of rapidly realigning the circadian rhythm of service members to the local environment, leading to improved sleep and performance. This device will continuously measure and collect physiological signals, and synthesize them into a continuous circadian rhythm estimate. The device should also be integrated with a light modulation component that could inject or block the portion of the light spectrum that regulates the circadian rhythm. The collected physiological signals, estimated circadian rhythm, and circadian light control information, as well as user input on self-assessed sleep quality and alertness, will be stored on the device to allow health professionals further evaluation.

DESCRIPTION: The Earth has a regular 24-hour pattern of daylight and darkness over most of its surface. Terrestrial species have adapted to this daily pattern by evolving biological rhythms, called circadian rhythms, which repeat at approximately 24-hour intervals. For humans, circadian rhythms are regulated and generated by a master clock located in the suprachiasmatic nuclei (SCN) in the hypothalamus in the brain. Lack of synchrony between the master clock in SCN and the external environment, referred to as circadian misalignment, can lead to circadian disruption, with potential detrimental consequences ranging from increased sleepiness and decreased attention span during the day, lower productivity, gastrointestinal disorders, to long-term health problems such as increased risk for cancer, diabetes, obesity, and cardiovascular disorders.

Service members are at particular risk for circadian rhythm misalignments, due in part to mission schedule, travel across time zones, and irregular sleep cycles. A safe method for rapidly adjusting their circadian rhythms to the external environment may alleviate the deleterious effects of this condition. The ideal system would either be a one-size-fits-all solution or include means by which it automatically calculates the appropriate treatment or dose for each individual or group of individuals exposed to the same circumstances.

COTS devices currently exist that monitor physiological signals such as body acceleration, pulse rate, body temperature, etc., but they do not directly estimate the circadian rhythm. There are also COTS devices such as Philips light panel that provides blue light to affect circadian rhythm, but they are self-administered and are not tied to measurement devices. An integrated solution of circadian rhythm estimation and light-based circadian rhythm will allow effective regulation of circadian rhythm and avoidance of circadian misalignment, leading to improved health, sleep and performance.

The goal of this topic is to leverage the large body of research literature on circadian rhythm and couple it to the advance in wearable/embedded device technologies to develop an integrated circadian rhythm regulation device.

PHASE I: Given the short duration of Phase I, this Phase should not encompass any human use testing that would require formal IRB approval. Phase I should focus on system design for rapid realignment of circadian rhythm to the external environment. At the end of this Phase, a working prototype of the device(s) and the application(s) should be completed and some demonstration of feasibility, integration, and/or operation of the prototype. In addition, descriptions of data syncing concept, interoperability concerns, and data storage and tracking should be outlined. Phase I should also include the detailed development of Phase II testing plan.

PHASE II: During this Phase, the integrated system should undergo human subject testing for evaluation of the operation and effectiveness of utilizing an integrated system and its impact on real-world outcomes of circadian rhythm regulation, sleep, and alertness. Accuracy, reliability, and usability should be assessed. This testing should be controlled, rigorous and account for the demands of military lifestyle and austere environments. Statistical power should be adequate to document initial efficacy, feasibility and safety of the device. This Phase should also demonstrate evidence of commercial viability of the tool. Accompanying the application should be standard protocols and procedures for its use and integration into ongoing programs. These protocols should be presented in multimedia format.

PHASE III DUAL USE APPLICATIONS: The ultimate goal of this topic is to develop and demonstrate a wearable device that can be utilized as a personal circadian rhythm regulation device by synthesizing physiological signals into a circadian rhythm estimate and adjusting circadian light input based on the estimate. This device should also seamlessly integrate with other peripheral device(s), web-based and Smartphone applications, and provide additional feedback and monitoring tools for long term health assessment. The Army Medical Command has significant interest in the results of Phase II, and the final system will be integrated into other Army informational systems such as Army Fit and AHLTA (Armed Forces Health Longitudinal Technology Application), supporting the Army Surgeon General's Performance Trial Pilot Program. In addition the system will be of interest to various commercial consumers for improving general health of shift workers and international travelers.

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KEYWORDS: Health, Circadian Rhythm, Wearable Device, Technology, Military Health, Activity, Sleep, Alertness

A14A-T010 TITLE: Cryogenic Low-Noise Amplifiers for Quantum Computing and Mixed-Signal Applications

TECHNOLOGY AREAS: Sensors

OBJECTIVE: Design, development, and packaging of compact integrated low-noise cryogenic amplifiers operating near the standard quantum limit for quantum computing and mixed-signal applications.

DESCRIPTION: Recently several innovative amplification techniques have been demonstrated for weak microwave signals encountered in the read-out of the quantum state of superconducting qubits (Refs. 1-4). These amplifiers operate near the standard quantum limit (SQL) and provide a means for high- fidelity readout of the quantum state of superconducting qubits. These amplifiers can also be used for the readout of semiconductor qubits. Another set of potential applications is the amplification of weak microwave signals encountered in mixed-signal applications (E.g., astronomy, deep-space communications). Amplification techniques that have been recently demonstrated and are of interest here include Josephson parametric amplifiers, Josephson parametric convertors, traveling wave amplifiers, and SQUID based amplifiers. While the demonstrated performance of these amplifiers in the research environment has been impressive, the amplification system is bulky and difficult to integrate with qubit and signal analysis circuits. This is because of the use of bulky components such as circulators and isolators. This topic seeks innovative design and packaging techniques that would result in small compact packages for these research amplifiers. The packages should allow for easy integration with qubit or mixed-signal circuits, robust operation, enable multiplexing, and operate within the space and environment of dilution refrigerators and cryostats. While this topic does not look for improvements to the performance of the research amplifiers, the new design and packaging should maintain their inherent performance (operate near the standard quantum limit).

PHASE I: Effort should focus on design, fabrication techniques, and proof-of-concept demonstration of critical system components and feasibility of the approach for a compact package while maintaining published amplifier performance. Simulations and simple experiments should be performed to demonstrate feasibility of the proposed approach. An example application should be identified and used for the proof-of-concept demonstration.

PHASE II: Finalize design and build prototypes of the device. Provide a demonstration deployment that validates the technology at a laboratory that does suitable qubit or mixed-signal analysis experiments. The Phase-II program shall provide a plan to transition the technology to commercial development and deployment, wherein amplifier packages are available for purchase by the user community.

PHASE III DUAL USE APPLICATIONS: The technology developed here has impact on the successful demonstration of quantum computing. The technology developed here is also anticipated to have broader impact, such as in astronomy and deep-space communications. Other applications that involve weak microwave signals could also benefit from this technology. Potential customers include researchers in universities, industry, and DoD laboratories; DoD aerospace and electronics contractors; telecommunications industry; and medical equipment manufacturers.

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Phys. Rev. Lett. 110, 173902 (2013).

KEYWORDS: Cryogenic amplifiers, Quantum computing, Mixed-signal circuits

A14A-T011 TITLE: Freeze Casting of Tubular Sulfur Tolerant Materials for Solid Oxide Fuel Cells

TECHNOLOGY AREAS: Materials/Processes

OBJECTIVE: Develop freeze casting techniques for tubular Solid Oxide Fuel Cells (SOFC) comprised of intrinsically tolerant fuel cell materials to enable use of JP-8 fuel.

DESCRIPTION: Future SOFC based portable energy systems will require the use of JP-8 fuel which can contain up to 3000 ppm sulfur. Current approaches to enable the use of JP-8 fuel include the use of adsorbent beds to remove the sulfur prior to fueling or onboard desulfurization units. These additional steps/units add logistical and tracking burdens or add cost and weight to the system. The need for intrinsically sulfur tolerant SOFC materials has been recognized for many years and sulfur tolerant materials have been demonstrated by multiple research teams at universities throughout the country, however, they have yet to be incorporated into stacks.

Sulfur tolerant materials remain at the university and button cell research level largely due to their low power densities. Adoption of intrinsically sulfur tolerant SOFC materials in portable systems for the military requires a dramatic improvement in power density. Recently researchers at NASA have demonstrated a dramatic increase in the power density of planar SOFCs by altering the microstructure through a freeze casting technique. To date, this technique has not been applied to tubular SOFC cells which have better thermal cycling characteristics. By combining intrinsically sulfur tolerant SOFC materials and freeze casting, there is an opportunity to prepare tubular SOFCs comprised of sulfur tolerant materials that will enable portable SOFC systems that can use JP-8 fuel with desirable start up times, cycle life, and system weight/power density.

PHASE I: Design, construct, and evaluate freeze cast tubular SOFCs that integrate sulfur tolerant materials. Characterize cell power density, sulfur tolerance, lifetime, mechanical properties, etc. Provide a detailed conceptual design of a 250-W (net) power system based upon the results generated in these efforts.

PHASE II: Design, construct, and evaluate a 250-W generator based upon the freeze cast sulfur tolerant tubular SOFC cells studied in Phase I. Deliver one unit to the Army for evaluation. The power system must be person portable and as compact and lightweight as technologically feasible (ideally less than 12 lbs). Assess cost and manufacturability of demonstrated technology.

PHASE III DUAL USE APPLICATIONS: Developments in fuel cell power sources in the 250-W range will have immediate impact on a variety of military and commercial applications such as battery charging as well as auxiliary power units for communication, recreational, or medical emergency equipment.

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KEYWORDS: Sulfur Tolerant, SOFC, Freeze Cast, JP-8, Fuel Cell

A14A-T012 TITLE: Biologically-Derived Targeted Antimicrobials for Textile Applications

TECHNOLOGY AREAS: Materials/Processes

OBJECTIVE: Develop biologically-derived antimicrobial molecules targeting selective killing of Corynebacteria and/or Staphylococcus aureus and approaches to apply the antimicrobials to textiles without a negative impact on original textile properties.

DESCRIPTION: Antimicrobial treatments are being utilized by the U.S. Army in a number of textile systems including T-shirts, socks and sleeping bag liners in an effort to control odor and reduce skin irritation, thus improving quality of life for the Warfighter. Current chemically-derived antimicrobials including metals (silver- and copper-based compounds), polyphenols, halamines and quaternary ammonium compounds have proven effective as antimicrobial treatments for textiles. However, the processing and use of these compounds results in production of environmental hazards, and these compounds suffer several deficiencies including lack of durability, deleterious impact on textile physical properties and high costs. Most importantly, the current chemical-based treatments possess broad-spectrum antimicrobial activity, which may contribute to the development of dangerous bacterial resistance [1]. Moreover, textiles treated with broad-spectrum antimicrobials non-specifically kill beneficial bacteria required to maintain skin health. The normal skin flora helps prevent pathogenic microbial colonization and growth by providing competition for space and resources and maintaining an acidic skin pH (pH ~5) [2]. Thus, novel antimicrobial compounds are needed to reduce environmental hazards and impart targeted bacterial killing to eliminate pathogenic microbes while maintaining beneficial bacteria needed to improve overall Soldier health and quality of life. Many biologically-derived molecules (e.g., bacteriocins, bacteriophage, phage lytic enzymes) have demonstrated effective antimicrobial activity with increased specificity relative to chemical-based systems and no associated environmental hazards, representing a potential new generation of selective antimicrobials.

The goal of this topic is to develop biologically-derived antimicrobials that demonstrate efficacy against the primary bacteria responsible for skin irritation and/or odor, while maintaining the viability of bacteria required for skin health when applied to military textiles that have direct contact with skin. Healthy skin is colonized by consortia of bacteria consisting of mainly Gram-positive bacteria from the genera Staphylococcus, Micrococcus, Corynebacteria and Propionibacteria [3]. For the purposes of this topic, the antimicrobial technology must selectively kill Corynebacteria, which is primarily responsible for malodor associated with sweat [4] and/or Staphylococcus aureus, which is associated with atopic dermatitis [2]. The antimicrobial technology must have no effect on bacteria required for skin health, including Staphylococcus epidermidis, Micrococcus and Propionibacteria.

PHASE I: Develop biologically-derived antimicrobial molecules that selectively kill Corynebacteria spp and/or S. aureus in a solution-based system. Demonstrate that the antimicrobial molecules have no detectable effect on bacterial strains/genera required for skin health as identified via literature survey, to include at a minimum S. epidermidis, Micrococcus and Propionibacteria. Demonstrate laboratory-scale production (>5 g) of the antimicrobial molecules and bactericidal activity (minimum 2-log reduction) against the target bacteria. Demonstrate that the developed antimicrobial molecules are not bactericidal or bacteriostatic against the non-target bacteria and do not exhibit cytotoxicity or hemolytic activity in vitro. Assess scalability and cost-effectiveness of the production approach.

PHASE II: Optimize the antimicrobial production approach developed in Phase I and demonstrate production of antimicrobial molecules in sufficient quantities for application to textiles. Develop approaches to apply antimicrobials to a 50:50 nylon:cotton blend fabric with no effect on the base material properties (e.g., tensile strength, air permeability, moisture/vapor transfer, and appearance). Demonstrate reproducible, selective killing of Corynebacteria spp and/or S. aureus while maintaining viability of beneficial skin microbes, including at a minimum S. epidermidis, Micrococcus and Propionibacteria on 50:50 nylon:cotton fabric using standard test methods such as AATCC TM100-2004 (Antibacterial Finishes on Textile Materials). Determine the minimum log reduction in bacterial load necessary to achieve the desired outcome (reduction of odor, occurrence of atopic dermatitis, or both) and the maximum log reduction in bacterial load achievable by the developed antimicrobial treatment. The antimicrobial application must be durable and reproducibly maintain efficacy after laundering for 20 cycles according to AATCC 135-2004 (Dimensional Changes of Fabrics During Laundering). The finished fabric must not present an environmental or health hazard (i.e., below toxicity threshold levels as identified by EPA and OSHA). Demonstrate that the antimicrobial application does not produce any negative effects due to prolonged direct skin contact in an acute dermal irritation study and a skin sensitization study conducted on laboratory animals. Demonstrate that the antimicrobial treated fabric does not exhibit cytotoxicity or hemolytic activity in vitro. Assess scalability and cost-effectiveness of the production approach. Additionally, a minimum of 3 square feet of antimicrobial fabric must be provided to the Army for independent assessment, along with a control sample (minimum of 3 square feet) lacking the antimicrobial agent.

PHASE III DUAL USE APPLICATIONS: The development of biologically-derived antimicrobial molecules with selective killing efficiency will support commercially-viable antimicrobial textiles with negligible environmental hazards associated with production and usage. Moreover, selective antimicrobials will prevent complications inherent with broad-spectrum antimicrobial compounds used for odor reduction and/or prevention of skin irritation. A variety of military textile materials would benefit from development of targeted antimicrobials including Army combat T-shirts, medical/hygiene wipes, ballistic boxers, Army combat socks, Army combat boots, combat surgical shelters, and combat sleep systems (linens, sacks, etc.). The civilian sector would also significantly benefit from the developed technology in the medical and athletic markets.

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KEYWORDS: antimicrobial, bio-derived, textile, fabric

A14A-T013 TITLE: Parallel Two-Electron Reduced Density Matrix Based Electronic Structure Software for Highly Correlated Molecules and Materials

TECHNOLOGY AREAS: Sensors

OBJECTIVE: To develop state-of-the-art parallel two-electron reduced density matrix (2-RDM) driven electronic structure software that will enable the study of strongly correlated many-electron molecules and materials with accuracy exceeding the wavefunction-based coupled cluster gold-standard (CCSDT)at a computational cost that is similar to density functional theory methods and scales polynomially with the size of the quantum system.

DESCRIPTION: The US Army has an urgent need to improve the operational energy situation for the soldiers. Toward this end, this topic seeks to develop 2-RDM computational methods which have the unprecedented ability to quantitatively describe the dynamical and non-dynamical correlation energy of quantum systems using currently available computer architecture. Such capability will provide chemists, physicists, and materials scientists with the ability to predict and design novel molecules and materials with properties optimized for serving as power sources and energy storage and transfer media.

The 2-RDM methods represent all of the electrons in any molecule or material with only two electrons by replacing the wave-function by the 2-RDM as the basic variable for quantum many-electron theory [1-2]. Unlike multi-reference wave function methods, the 2-RDM methods have a polynomial scaling with system size, which has major implications for the computation of strongly correlated molecules and materials. The National Research Council ranked the development of 2-RDM methods as one of the top ten outstanding problems in chemical physics [3]. With previous funding support from the Army Research Office, recent major advances in theory and optimization have realized new, generally applicable 2-RDM methods with proven applications to studying strong electron correlation in quantum phase transitions, quantum dots, polyaromatic hydrocarbons, firefly bioluminescence, light harvesting, and metal-to-insulator transitions [1-6]. This Army STTR topic aims to transition previous 2-RDM method development into user-friendly, parallel software that can be implemented by a wide variety of scientists both within and outside of DoD for solving current problems in energy transport, storage, and release. Importantly, such problems may not be solvable with current coupled-cluster wave-function based methods (e.g., CCSDT) due their extremely intensive computational demands and certain limitations for describing the non-dynamical correlation energy.

Proposed research will develop state-of-the-art parallel 2-RDM-driven electronic structure software for many-electron molecules and materials. The 2-RDM software may exploit opportunities for traditional and stream parallelism at the algorithm level.

PHASE I: In the Phase I effort, specific 2-RDM-based methods will be selected for inclusion in the software, semidefinite programming algorithms will be selected, parallel software elements to be shared by all the methods for portability and efficiency will be planned and prototyped, and revolutionary technology will be planned and prototyped that automatically makes computational decisions for users including “decision smart” and “auto parallel” technologies.

PHASE II: The goal of Phase II will be to build a modern, parallel 2-RDM-based electronic structure software packages for strongly correlated molecules and materials. In the Phase II effort, a suite of parallel software elements will be built to provide a modern integrated environment that maximizes efficiency, portability, maintenance, and expandability. Multiple 2-RDM-based methods will be programmed and integrated on the foundation of the parallel software elements. State-of-the-art semidefinite programming algorithms, as well as other modern optimization algorithms, will be implemented. The resulting prototype of the software will be demonstrated for DoD government parties for their assessment. Comprehensive documentation will be prepared for users, and theoretical and computational results from the software will be published as bench-mark data in the peer-reviewed literature.

PHASE III DUAL USE APPLICATIONS: The prototype 2-RDM-based software developed under this topic will enable unprecedented quantitative predictions on highly correlated molecules and materials, especially excited states, open systems, and time-dependent systems. It will have advanced features to parallelize users’ tasks automatically. The software will lead to new military capabilities for the design of strongly correlated materials for energy capture, storage, and transfer as well as for tunable thermal and thermo-electric properties, the prediction of spectroscopic signatures of chemical agents, and the processing and analysis of noisy visual, audio, or electromagnetic data for advanced sensing by semidefinite programming. The product will be equally useful for related analysis in commercial applications. Both the parallel 2-RDM-based electronic structure software and the parallel large-scale semidefinte programming will be commercialized for a wide customer base spanning the government, industrial, and academic research centers.

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KEYWORDS: strongly correlated molecules materials, energy and information transfer, polynomial scaling of computational cost, advanced sensing, semidefinite programming

A14A-T014 TITLE: Flexible Ionic Conducting Membranes for Anode Protected High Energy Density Metal Air Power Sources

TECHNOLOGY AREAS: Materials/Processes

OBJECTIVE: To develop ionically conducting monovalent and divalent cation conductors that provide high ionic conductivity, and are chemically and electrochemically stable for use in metal air cells. In order to accommodate internal stress and strain developed during use as well as externally applied forces either mechanical or thermally induced the developed membranes are required to be mechanically flexible to allow for use as an ionically conductive protective layer on metal anode materials in electrochemical air cells.

DESCRIPTION: The electrochemical coupling of a reactive anode to an air electrode provides an electrochemical cell with an inexhaustible cathode reactant and, in some cases, very high specific energy and energy density. (1,2) The capacity limit of such systems is determined by the mass of the anode (Ampere-hour capacity) and the technique used for handling and storage of the reaction product. As a result of this potential performance, significant effort has gone into metal/air battery development. In a metal air electrochemical cell lithium, calcium, and magnesium have attractive energy densities. Lithium/air, (3,4) calcium/air, and magnesium/air batteries (5,6) have been studied, but cost and technical hurdles such as anode polarization or instability, parasitic corrosion, non-uniform dissolution, and safety have limited the development of commercially viable products. (1,2) The anodes for alkali and alkali-earth metal-air electrochemical cells are typically metal on a current collector. To avoid performance degradation as a result of anode polarization or instability, parasitic corrosion, and non-uniform dissolution a protective layer is often employed in the cell design. Both polymers and ceramic or glass ionic conductive materials have been used for this protective layer. (7-10) These materials have performed well but typically compromise one of the technical performance areas. An ideal protective film will have; 1) high ionic conductivity (0.01 S/cm at 25C) and low electrical conductivity (~0) over a wide temperature range (-30C to 60C), 2) good thermal (-40C to 95C), electrochemical (>5V) and chemical (oxidation and reduction) stability, and 3) good mechanical properties (flexibility and fracture or puncture resistance).

Proposals shall describe efforts leading to the development of a mechanically stable membrane capable of ionic transport of lithium, sodium, magnesium or calcium cations that have; 1) high ionic conductivity (0.01 S/cm at 25C) and low electrical conductivity (~0) over a wide temperature range (-30C to 60C), 2) good thermal (-40C to 95C), electrochemical (>5V) and chemical (oxidation and reduction) stability, and 3) good mechanical properties (fracture and puncture resistance and flexibility). The goal of the membrane is to provide an anode protective layer for an alkali or alkali-earth air electrochemical couple.

PHASE I: Develop a mechanically stable membrane capable of ionic transport of lithium, sodium, magnesium or calcium cations that have; 1) high ionic conductivity (0.01 S/cm at 25C) and low electrical conductivity (~0), 2) electrochemical (>5V) and chemical (oxidation and reduction) stability, and 3) good mechanical properties (fracture and puncture resistance and flexibility).

PHASE II: Develop and demonstrate a prototype electrochemical system using a mechanically stable membrane capable of ionic transport of lithium, sodium, magnesium, or calcium cations in a realistic environment. Conduct testing to prove feasibility over extended operating conditions. The goal of this phase is 1) high ionic conductivity (0.01 S/cm at 25C) and low electrical conductivity (~0) over a wide temperature range (-30C to 60C), 2) good thermal (-40C to 95C), electrochemical (>5V) and chemical (oxidation and reduction) stability, and 3) good mechanical properties (fracture and puncture resistance and flexibility).

PHASE III DUAL USE APPLICATIONS: This system could be used in a broad range of military and civilian applications where autonomous operation for extended times are required. Perimeter surveillance and intrusion sensors are examples of applications that will benefit from improvements in the metal air systems that will be afforded by successful development of anode protective membranes.

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KEYWORDS: Ionic conducting membrane, Cation conductor, Metal air electrochemical cell, Alkali and alkali-earth air cell

A14A-T015 TITLE: Tunable High-Power Infrared Lasers for Standoff Detection Applications

TECHNOLOGY AREAS: Chemical/Bio Defense

OBJECTIVE: The objective of this topic is to advance the state of the art in broadly tunable infrared sources for remote-sensing applications. In particular, high-power sources that can be wavelength-tuned extremely rapidly are needed for the detection and identification of chemical vapors, aerosols, residues on surfaces.

DESCRIPTION: Recent advances in the performance of candidate sources lend themselves to commercial success in a variety of applications, but have not made the jump from the laboratory to industry. Technology development and industrial tooling in the production of high-power rapidly tunable infrared sources covering the long wave infrared (LWIR) region have the potential to revolutionize current infrared analysis and remote sensing methods. Modern infrared sensing tools rely on Fourier transform infrared (FTIR) spectrometry/spectroradiometry or carbon dioxide laser sources applied to differential absorption light ranging and detection in order to achieve standoff detection capabilities for threat materials including chemical and biological agents. Integration of such technology into compact and rugged field equipment poses significant challenges, yielding system concepts that are prohibitively expensive and limited in range and sensitivity. Recent advances in quantum cascade laser (QCL) technology offer promising alternatives to conventional approaches that could shift the paradigm in remote sensing system concepts and achieve unprecedented performance.

Commercially available QCL technology typically utilizes a single laser that is incorporated into an external cavity with a diffraction grating to select an emission wavelength within the emission bandwidth of the laser chip. However, since wavelength tuning requires mechanical motion of bulk optical components, tuning between two arbitrary wavelengths is relatively slow and the opto-mechanical assemblies are not robust against the rigors of operational military use of the technology. Furthermore, the average power available from a single device is constrained by their high thermal resistance such that most commercial sources are limited to peak powers of a fraction of a watt. For many remote sensing applications, the slow speed of wavelength tuning, an optomechanical assembly that is prone to vibrations, and limited laser power makes it difficult to transition this technology to fielded systems. Alternative technology includes but is not limited to a frequency agile continuous wave carbon dioxide laser incorporating optical parametric oscillators to produce equivalent power outputs across the range of target wavelengths.

PHASE I: Design a compact, rugged, and high power (>5Wpeak, >0.5Waverage) laser source that covers the ~7-11 micron band with a spectral resolution of <5 cm-1, with a tuning speed between wavelengths of <1 microsecond with single mode output in both the longitudinal and the transverse dimensions while maintaining a side-mode suppression ratio (SMSR) of at least 20 dB. Size constraints on the Next Generation Chemical Detector limit the weight of the sensor to 4.5 kg, which would include all power supplies, batteries, optics, detectors, and electronic controls and interfaces; hence the laser component, controller, and power supply must be integrated into a very small volume and weight in order to make it feasible to build an integrated sensor within these constraints. The emphasis should be on tooling for manufacture and production of the source at some reasonable production scale (e.g., produce 6 laser sources per year initially). All of the wavelengths emitted from the source must be spatially overlapped to have a beam quality of <2x the diffraction limit. In the case of QCL arrays, upwards of 100 lasers may be necessary to cover this broad bandwidth with the desired spectral resolution, and the laser outputs could be spatially overlapped using wavelength beam combining techniques. The product of the Phase I study should entail a comprehensive systems production approach that details the costs associated with the production and commercialization of the technology.

PHASE II: Implement the Phase I laser production process to produce at least four multilaser sources and develop a cost, size, weight, and power analysis for the system. Deliver a source and controller capable of lasing with > 5Wpeak and >0.5 Waverage of output power across the 7-11 micron band at a <1 microsecond switch rate between wavelengths and with a spectral resolution of <5 cm-1. Demonstrate a path towards tooling the manufacturing process for production of the high power laser source.

PHASE III DUAL USE APPLICATIONS: High power laser sources covering the long wave infrared region would afford a paradigm shift in the way infrared remote sensing, atmospheric sounding, and environmental monitoring research is done. Applications of this technology would not be limited to remote sensing: proximal imaging for trace contaminants or materials integrity or ultrasensitive cavity ringdown spectroscopy applications would realize significant market potential in industrial process control and medical diagnostics.

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KEYWORDS: infrared remote sensing, quantum cascade laser, frequency agile laser, standoff detection, spectroscopy

A14A-T016 TITLE: Innovative Wound Regeneration Support Approaches to Enable Rapid Treatment of Wounded Warfighters

TECHNOLOGY AREAS: Biomedical

OBJECTIVE: There is a strong military need for an active wound dressing treatment that combines traditional wound coverage with innovative wound regeneration support approaches to enable rapid treatment of wounded Warfighters, e.g. by negative pressure application, wound irrigation, oxygenation support, regeneration solution perfusion.

DESCRIPTION: Warfighters who suffer extreme traumatic wounds in the line of duty experience extended healing times with existing standard of care medical practices. Such wounded military Warfighthers are prone to morbidity because of severe infection and other resulting physiological health related complications. Standard of care treatment for traumatic wounds is often topical bandages, solutions, or negative pressure wound therapy, a therapeutic technique using a vacuum dressing to promote healing in acute or chronic wounds and enhance healing of first and second degree burns (1). The therapy involves the controlled application of sub-atmospheric pressure to the local wound environment using a sealed wound dressing connected to a vacuum pump with the ability to instill medication or other perfusion solutions. Controlled studies and clinical evidence has shown the therapy to be effective (2), however, no decentral mass exchange is provided and there is a discontinuous perfusion supply (3). Furthermore, negative pressure wound therapy does not provide constant oxygenation, pH regulation, electrolyte balance, detoxification, and nutrition (4). In a standardized controlled swine animal model, Graham et. al evaluated eleven commercial-off-the-shelf advanced wound care products for efficacy in improving chemical burns using a variety of non-invasive bioengineering methods, histopathology, and immunohistochemistry. Of the eleven treatment adjuncts examined, the most statistically significant in healing chemical burns included Vacuum Assisted ClosureTM, Amino-Plex®, and ReCell® Autologous Cell Harvesting Device (5). An approach that combines all three of these treatments while regulating the homeostasis and nutrition media to the wound bed could potentially accelerate healing times, prevent severe infections, and reduce scarring.

It is the goal of this topic to explore the feasibility of developing or adapting an existing device in development that can meet the military’s need for improved advanced wound care treatment. The device should be accessible by trained medical personnel. Finally, the device should demonstrate a clear improvement in wound healing as compared to control therapies. Design of such a system for advanced wound care is expected to be technically challenging, and will require innovative and creative approaches to meet the technical goals. Significant flexibility in formulating an approach will be considered. An approach that can be developed and fully commercialized within 2-5 years is sought.

PHASE I: Develop design plans and conduct in vitro experiments of an advanced wound care support therapy. Electronic engineering plans should be generated that allow 3-dimensional, rotational views of all components of the proposed system. A document describing the proposed operation and functionality of the system should also be generated. Furthermore, this phase should include a plan for development, clinical validation, regulatory strategy, concept of the proposed device, and a literature search to support feasibility.

PHASE II: Develop and demonstrate efficacy of a working prototype based on Phase I work suitable for FDA clinical trials. Conduct in-depth statistically significant testing in an appropriate in vivo animal model to show functionality, safety, and efficacy. Identify clinical sites for validation and primary investigators. Arrange for preliminary talks with FDA regarding regulatory path (at least pre-IDE, preferably IDE). Finalize plans for pivotal trial protocol.

PHASE III DUAL USE APPLICATIONS: Conduct a statistically significant safety and efficacy pivotal trial at a military treatment facility and gain FDA clearance or approval.

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KEYWORDS: Medical management, Military trauma, Acute, Chronic, Wound Healing

A14A-T017 TITLE: Multiple Hit Performance of Small Arms Protective Armor

TECHNOLOGY AREAS: Human Systems

OBJECTIVE: Develop methods for predictive modeling of body armor performance against closely spaced ballistic impacts from burst fire.

DESCRIPTION: Many automatic combat rifles have a "burst fire" mode that enables the shooter to fire multiple rounds with a single pull of the trigger. Bursts of small arms fire create the risk of multiple closely spaced impacts to body armor. A single ballistic impact may locally weaken the body armor material causing any subsequent impacts near the initial impact location to be less survivable. A better understanding of the spatial distribution of burst fire impacts and the relationship of that distribution to survivability will assist materiel developers with armor design, material selection, and requirements generation.

The effects of close impacts on body armor are poorly understood and may depend on multiple interacting factors. These factors could include; the arrival sequence and pair-wise distance between impacts, the attributes of the rifle and projectile, kinetic energy, standoff distance, location of impact on the armor system, and the materials used in the armor system (e.g. ceramics, fibers). The spatial distribution of burst fires may exhibit spatial dependency due to the effect of recoil on the rifleman's grip/aim, marksmanship skill, cognitive state, and the purpose of the fires (sweeping area fire vs. point aiming). Factors contributing to spatial dependency of burst fires are unlikely to be observed under highly controlled laboratory conditions using testing rigs and inertially stabilized gun barrels.

Traditional measures of shot group dispersion (such as standard deviation around the aim point or vertical/horizontal dispersion) may implicitly assume a bivariate Gaussian distribution with independent realizations and thus fail to capture the existence of spatial dependence in the true distribution.

This solicitation seeks a modeling methodology with predictive/inferential capabilities, that is generalizable across a wide range of future body armor configurations, materials, and combat scenarios to enable answering important questions such as, conditional upon a ballistic impact at a certain location: (1) predict armor performance at that location, (2) predict the likelihood of subsequent impacts nearby (3) given damage at a location predict performance for a subsequent impact at a different location, and (4) integrating 1/2/3, enable rigorous probabilistic risk assessments of armor performance against burst fires to enable better decision making about armor design, material selection, and requirements generation.

PHASE I: In Phase I the following shall be accomplished:

1) Identify and determine the suitability of candidate methods for modeling the spatial distribution of small arms burst fires and its relationship to armor performance. The techniques should enable assessment of contributing factors to the behavior of the spatial distribution itself as well as to performance outcomes.
2) Perform a comprehensive analysis of the proposed methodology's statistical foundations and potential computational implementation. Possible areas for analysis may include uncertainty quantification, parameter identification, estimation methods, hypothesis testing, and ability to discriminate between different forms of spatial dependency in both burst fires and armor performance.
3) Identify data collection and instrumentation strategy for collecting relevant experimental data, including data to support estimation/identification of the model parameters and model discrimination.
4) Identify methods of reporting model data that would be useful to materiel developers making decisions about armor design, material selection, and requirements generation.

Deliverables shall include a technical report, collaboration plan with university researchers, and may include a proof of concept implementation in a commonly available scientific programming language.

PHASE II: In Phase II the offeror will develop, test and demonstrate proposed methodology in software. Because of the expense and sensitivity of collecting armor performance information, the offeror may be asked to work with simulated data provided by Army research activities. The following shall be accomplished:

1) Demonstrate an "end to end" modeling process to accomplish the objectives mentioned in the description: (1) predict armor performance at that location, (2) predict the likelihood of subsequent impacts nearby (3) given damage at a location predict performance for a subsequent impact at a different location, and (4) integrating 1/2/3, enable rigorous probabilistic risk assessments of armor performance against burst fires to enable better decision making about armor design, material selection, and requirements generation.

The ideal solution would address all facets of the problem, however recognizing different skill sets; we would entertain proposals that are more weighted to (1) spatial distribution of burst fires or (2) spatial dependence of armor performance.

2) The method shall be documented, implemented in software and made available to interested government users for evaluation. Special attention will be given to numeric stability, incorporation of new predictor variables or improved representation of existing variables, speed vs. accuracy tradeoffs, and processing of larger data sets on DoD high performance computing (HPC) platforms if needed by the methodology.

PHASE III DUAL USE APPLICATIONS: The end state for this STTR would be the delivery of software which enhances the ability of material developers to specify and design body armor by enabling a better understanding of the performance of armor/armor materials to close ballistic impacts. It could have R&D transition partners in ARL/NSRDEC for Solider/Individual protection and within prime contractors for personal protective equipment.

Outside of the DoD research application, the capability to predict a quantity of interest as a function of spatial location and other predictive spatial/non-spatial variables has commercial interest because it can used by academic and applied workers in geological, oceanographic, ecological, econometric, insurance and epidemiological applications. Example applications include mapping of oil field productivity, predicting optimal retail site locations, and locating areas of increased risk of disease outbreaks or insurance losses.

The technology developed under this topic will substantially improve the ability of materiel developers to design and specifiy requirements for body armor by improving their understanding of the relationship between close impacts and armor performance. Potential R&D transition partners include ARL/NSRDEC for Solider/Individual protection and prime contractors for personal protective equipment. The underlying technology could also be applicable to the design of vehicular armor.

The capability to predict a quantity of interest as a function of spatial location and other predictive spatial/non-spatial variables has commercial interest because it can used by academic and applied workers in geological, oceanographic, ecological, econometric, insurance and epidemiological applications. Example applications include mapping of oil field productivity, retail site locations, disease outbreaks, and insurance losses.

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KEYWORDS: Body armor, spatial statistics, modeling and simulation

A14A-T018 TITLE: Intelligent Terrain-Aware Navigation and Mobility of Unmanned Ground Vehicles Operating Under Varying Degrees of Autonomy

TECHNOLOGY AREAS: Ground/Sea Vehicles

OBJECTIVE: To develop innovative methods and software that should rapidly and robustly plan safe paths of travel for a vehicle through its surrounding environment, while explicitly reasoning about terrain difficulty and variability, and vehicle mobility. The methods and tools to be developed will provide navigation assistance over a range of vehicle control modes, ranging from manual teleoperation to semi-autonomy to full autonomy, and will enable an “extreme mobility” capability.

DESCRIPTION: Researchers at the Army and in the terramechanics research community have developed various methodologies for assessing and predicting the mobility of vehicles traveling over natural terrain. Such methodologies include the NATO Reference Mobility Model (NRMM), and vehicle-terrain interaction (i.e., terramechanics) models based on the work of Bekker and Wong [1-4]. These mobility prediction methodologies are empirical or semi-empirical formulations that rely on detailed analysis of the vehicle running gear’s interaction with terrain. Mobility predictions derived from these models unavoidably contain uncertainty due to variability in soil composition, density, moisture content, morphology, and other factors that are difficult to measure in laboratory or field conditions.

In parallel, researchers have developed a wide range of vehicle motion planning and control algorithms to assist or enable teleoperated and autonomous vehicle navigation capabilities [5-8]. In an effort to reduce computational complexity (and thereby enable on line, i.e. real time use), the vast majority of these algorithms employ highly simplified vehicle and terramechanics models to describe all possible vehicle-terrain interaction scenarios. However, it is well known that both the vehicle’s dynamics and terrain physical properties can strongly influence a vehicle’s dynamic response. For example, the dynamics of a vehicle travelling on soft soil can be very different compared to the dynamics of a vehicle travelling on asphalt. Vehicle mobility is also affected by travel over steep slopes, and over rough surfaces [9]. In addition, many vehicle models employed in planning algorithms only consider rigid body vehicle dynamics, and do not consider important suspension effects. Finally, both terrain and vehicle model parameters typically contain uncertainty, which are often ignored in the motion planning literature. It has been shown that modeling simplifications, model parameter uncertainties, uncertain measurements, and disturbances can cause substantial deviations from an initially planned evasive maneuver. A planned trajectory, which can guarantee the safety of the vehicle under ideal conditions, can become unsafe when these real-world effects are considered [10].

Consequently, due to the simplicity of the vehicle and terrain models employed in state-of-the-art planning and control algorithms, it is unclear whether they can yield safe and reliable unmanned ground vehicle (UGV) mobility performance in complex, deformable terrain, which cannot be accurately modeled with simplified terramechanics and vehicle models.

There exists a need for vehicle motion planning algorithms that explicitly represent the complexity and variability inherent in vehicle-terrain interaction phenomena, and yield navigation strategies that are robust to this variability. To achieve this, such algorithms might (for example) capture variability by performing Monte Carlo simulations of embedded multibody dynamics vehicle models coupled with classical terramechanics models (e.g. Bekker-Wong models). An alternative approach might rely on embedded statistical models of terrain variability that are derived from laboratory test data. A third approach might attempt to learn key terrain properties during vehicle motion, by examining vehicle responses to known inputs. In all cases, computational complexity is a key issue.

Development of a “terrain aware navigation” capability will enable improved vehicle performance over a range of vehicle control modes. For example, in manual vehicle teleoperation scenarios, the planning algorithm could run as a background process, and safe (or unsafe) routes could be presented as visual overlays on an operator control unit (OCU), as a driver aide. In semi-autonomous vehicle teleoperation scenarios, the planning algorithm could again be run as a background process, and safe/unsafe regions in the environment could be mapped to assistive controls applied to the vehicle, to help the operator safely guide the vehicle. In fully autonomous scenarios, the planning algorithm could form the basis of an autonomy kernel that robustly reasons about terrain difficulty and uncertainty.

PHASE I: Work in Phase I would involve investigation of a method(s) for statistical modeling of terrain variability that can be integrated with a novel or existing motion planning framework. This work may include efficient terramechanics and/or vehicle model formulation, or statistical descriptions of terrain complexity and variability. A description of a planning architecture that explicitly represents terrain and vehicle properties will be described.

Another component of Phase I research would involve identification of a suitable simulation-based testbed for algorithm development and demonstration. This testbed should exhibit the ability to model vehicle dynamics and deformable terrain properties, and should allow integration of customized motion planning and/or control algorithms. It should also allow modeling of standard robotic sensors (i.e. LIDAR, GPS). A feasibility study of the terrain-aware navigation algorithm will be performed and a proof-of-concept simulation will be demonstrated in one or more (simulated) control modes (i.e. manual teleoperation, full autonomy, and some intermediate level of supervisory control).

PHASE II: Phase II would focus on further development, implementation, testing, and characterization of the terrain-aware navigation algorithm formulated in Phase I. Properties of the terrain-aware navigation algorithm such as computational complexity and optimality will be explored. The performance of the method will be characterized over a range of terrain conditions in a variety of scenarios, and compared to a baseline method that employs a naïve planning approach that does not rely on sophisticated terrain and vehicle models. Also in Phase II, investigation into the properties of the closed loop system composed of the vehicle, control system, and operator will be performed, with an aim of studying key variables affecting vehicle performance. Such variables include communications latency and sensing system accuracy, among others. Vehicle performance may be measured with metrics related to mobility, power consumption, and robustness, among others. The deliverable of Phase II will be a prototype software implementation of the intelligent mobility algorithm on an experimental robotic ground vehicle.

PHASE III DUAL USE APPLICATIONS: Work in Phase III would focus on collaborating with Army personnel to transition the developed navigation software to an Army-relevant UGV platform for operational testing. The developed software would be integrated with on-board UGV sensors. The software would be tested in a variety of scenarios in various environmental conditions to evaluate its accuracy and robustness, and to demonstrate its effectiveness to various Army stakeholders.

The proposed software could also be applied to civilian mobile robotics applications that require robust mobility in challenging terrain. These include hazardous site inspection/clean up, search and rescue, and tasks in the forestry and mining industries.

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KEYWORDS: Mobility, unmanned ground vehicles, vehicle-terrain interaction, terramechanics, autonomy, teleoperation, control, sensors, uncertainties, vehicle dynamics, high fidelity, real time